Educational Technology and its Environmental Impacts

Ethical considerations in the adoption of technology at scale using life cycle cost analysis and total cost of ownership approaches

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Educational Technology Consequences
Environmental Ethics
Scaling Up Technology Use
Technology Adoption
Total Cost of Ownership

As climate change driven by human consumption in capitalist economies continues to increase, instructional designers must be aware of the consequences of their technology acquisition decisions for the environment. Much of our ecological impact hides behind product ordering interfaces with simple pricing; however, the costs are present from the moment we select tools. This chapter aims to depict educational technology decisions made by instructional designers and educators as ones infused with ethical questions and consequences in the globalized supply chain and throughout the life cycle of each device *employed. Taking an indigenous worldview towards sustainability, coupled with an engineering life-cycle cost analysis that incorporates environmental considerations, we illustrate the questions facing instructional designers who seek to consider their technology choice impacts more ethically regarding the environment and those involved in the process of computer manufacture. Finally, we offer recommendations for mitigating ecological harm after the decision to acquire new learning technologies.*

Introduction

In 2015, an international team of 18 researchers claimed that "four of the nine Planetary Boundaries have already been crossed [. . .] the climate has already changed, the biosphere has lost its integrity, the land-system has been altered and the biogeochemical cycles have been corrupted" (Steffen et al., 2015, as cited in Saratli, 2017). Planetary boundaries are the ecological constraints on human development, such as freshwater use, chemical pollution, and climate change (Clift et al., 2017). Exceeding these boundaries is likely to lead to agricultural, environmental, and civilization collapse over time, meaning we should attend to how we can reduce our impacts on each, especially since energy use negatively impacts many (Sovacool et al., 2022), mining pollution (Flexer et al., 2018; Phillips, 2016), transportation (Su & Sun, 2019), and other aspects of information technologies acquisition and use (Levinson, 2009).

As humans, we often seek technological solutions to common social challenges, such as the need to foster critical thinking in members of a society or educate a future workforce. Further, we must be mindful of our impacts on the world around us as we cope with new global challenges in an ever-changing world under threats from climate change and political unrest resulting from an unsustainable economic model. Our energy-intensive, capital-intensive, global supply-chain-focused distributive business approach resulted in adopting technology at a scale the world has not previously experienced. With a focus on lowest cost and highest efficiency production models, there remains a failure to consider the environmental and ethical concerns that arise with the rapid adoption and intensive use of information technologies that require additional scrutiny ranging from surveillance capitalism to misapplication of digital assessment (Krutka et al., 2021). This chapter aims to explore an increasingly important aspect of technology adoption largely unexplored in ethics of educational technology discussion; that is, the environmental costs to the planet resulting from adopting learning technologies at scale.

For example, 1:1 laptop initiatives that provide a personal device to each child for learning value also carry environmental costs with their manufacture, transport, use, and later elimination (Warren et al., 2022). Total cost of ownership calculations do not commonly include these expenses made by organizations (Ellram, 1995). Further, increased energy use from device adoption and associated pollution (e.g., carbon dioxide, methane, etc.), related toxic e-waste (Kitila, 2015), and other related negative consequences from climate change (Crimmins et al., 2016) are an increasingly costly outcome of technology use. Today's economic model is "dependent on resource exploitation that is structured so that such exploitation seems the only means of survival [. . .] however, we must also recognize that the earth has an inherent value, beyond human needs" (Alfred, 2009, p. 85). Failure to recognize this inherent value noted by Alfred, leads to unsustainable mindsets wherein there are no resources available for future generations and an uninhabitable planet as the air, water, and soil become increasingly destroyed through mining, transportation, energy use, and other exploitation that benefit only current generations. This exploitation and harm often extend into the creation and disposal of the educational technologies we use. However, it is rarely discussed in many articles today that propose using more new tools. Such hardware devices are made of processed materials extracted from the earth and often powered by energy created by burning polluting fossil fuels. Our positive intention as educators for a tool's use does not reduce their inherent harms because technology manufacturers use the same methods rooted in a linear, globalized, largely opaque supply chain for both office and educational technologies.

It is equally important to consider other ethical needs, given that educators are responsible for making good choices about the tools they adopt to ensure strong learning outcomes and no harm to students. With today's climate, it becomes increasingly important to consider the environmental impacts of our technology choices as part of that ethical responsibility to provide students with a sustainable future. This chapter examines the environmental impacts on communities from the manufacture, transport, use, and disposal of educational technologies individually and in aggregate as deployed at scale in different learning contexts. From these findings, we propose there is an ethical need to use the market power of educational institutions at scale to pressure manufacturers to engineer devices to be upgradable and longer lasting, use less environmentally harmful production techniques, lobby for a right to repair existing devices, while also being more mindful about the consequences of our educational technology choices from the mining of raw materials needed to construct them through disposal phases of the supply chain. In addition, we provide guidance regarding how to mitigate the environmental harms of educational technology once chosen by designers or instructors.

Background

The field of educational technology is increasingly aware of ethical issues related to how our tools impact student and instructor privacy, create imbalanced power relationships created with big data and surveillance, and other issues that have not been discussed significantly in the past (Krutka et al., 2021). However, as the complexity of these tools grows, the need to be aware of their use consequences and develop an ethical attitude towards them is an increasing focus of discourse in instructional designs that require technologies to support teaching, learning, and training (Moore, 2013). However, much of the current focus is on using technologies already produced and their psychological impacts on learners. However, few studies focus on the antecedents of use, especially regarding the environmental impact of these technologies, starting from the acquisition of raw materials to the disposal of devices at the end of life. At every stage of the supply chain and use, there are human and environmental impacts that we are often unaware of because they hide behind brands, delivery companies, and impressive packaging. However, the actual costs are not transparent and, therefore, not part of our technology expense calculation. Unfortunately, as the earth's climate continues to change, if we are to behave ethically as social scientists recommending the use of technology and as practitioners implementing them, then improved awareness is necessary of the impacts of our educational tools on the environment and the people who produce them.

Human Contributions to Climate Change

A major contributor to climate change is the creation and use of today's technologies, ranging from fossil fuel-propelled ships and cars to computers of all sizes (Hill, 2017; Phillips, 2016; Joshi, 1999). Because today's capitalist economies and organizations are focused primarily on consumption, the operations of companies that lead to the technology in front of us tend to be hidden along with their environmental impacts. Building a computer requires mining raw materials that require high amounts of polluting energy use (Valero & Valero, 2020; Farjana et al., 2019), leading to greenhouse gas emissions (Liu et al., 2016) and toxic metals released, such as mercury and cadmium that can damage local groundwater (Birch, 2016; Sankhla et al., 2016), and soils (Jeong et al., 2021; Wang, 2015; Glodek et al., 2010). Every stage of the computer manufacturing supply chain that provides schools and students with devices has environmental consequences, contributing to climate change partly because of the economic philosophy that drives today's consumption-based culture.

Ethics and the Environment

In this section, we discuss the ethics of the environment from the perspective of economic philosophy and how human choices impact the world. In addition, we present examples of consequences of policy decisions (e.g., globalized technology production and reclamation) on human health in both local and distant countries. We frame the ethical considerations of technology, educational or otherwise, from the context of two different views of environmental ethics used to guide decision-making: exploitation and stewardship.

Different concepts of justice: Exploitation or responsibility to the land and its people

Alfred (2009) explained that the most common form of distributive social justice supported by sovereign states and their economies is rooted in capitalist worldviews. This conception focuses on growing businesses and industries to provide people with jobs as financial support. Capitalist philosophical and economic approaches tend to focus on natural resource extraction (e.g., fish, rocks, trees) to produce commodities with a value calculated only in dollars, with little consideration of the consequences of resource exploitation for the earth or the people in communities where it takes place (Birch, 2016). The earth's value to those ascribed to this capital extraction-focused philosophy is based primarily on aspects of the planet to exploit and distribute resources to humans. While generally useful for this purpose, capitalist societies commonly measure these resources as monetary gains provided through use or non-use to those who control natural resources in terms of total economic value with stated preference methods (Harris & Roach, 2018). In this context, business organizations only value and are designed to generate knowledge that supports environmentally extractive work practices; as such, managers tend not to choose environmental policies, technologies, and processes with long-term sustainability, focusing instead on building supply chains for short-term profits (Long, 2021) and risk avoidance (Er Kara et al., 2021). The language of business philosophy in this perspective commonly employs the words explore and exploit, dating back to the 1960s (Levitt, 1965), and natural resources mining continues to do so (Long, 2021; Dino et al., 2020; Tutak, 2019). With this colonialist exploitation mindset, environmental sustainability is, at best, a secondary consideration. Today's social and business viewpoint is rooted first in achieving a profit or seeking solutions to environmental problems framed in government funding that mitigates possible financial losses for companies responsible for environmental harm, rewarding them for participating in cap and trade or green bond schemes (Long, 2021). However, these approaches provide little evidence that they reduce environmental damage, redistributing the harms from one region to another (Chan & Morrow, 2019); this approach often helps companies further exploit the climate crisis (Long, 2021).

The capitalist economic approach to justice contrasts with that of indigenous philosophies rooted in the view that "the earth was created by a power external to human beings, who have a responsibility to act as stewards, since humans had no hand in making the earth, they have no right to possess or dispose of it as they see fit – possession of land by humankind is unnatural and unjust" (Alfred, 2009, p. 84). In the capitalist perspective, Alfred noted at the outset of his earth-focused manifesto that the earth's exploitation is viewed as ethical by society because it supports the distribution of its resources for the benefit of humans, though unevenly. By contrast, the traditionalist indigenous view "recognize[s] a responsibility to participate in the economy with the intent of ensuring the long-term health and stability of people and the land; in this context, development for development's sake, consumerism, and unrestrained growth are not justifiable" (Alfred, 2009, p. 85). We assert that the sustainable, indigenous view is more in keeping with the efforts of today's instructional designers who believe in the inherent value of their learners and instructors.

This chapter is further grounded in an idea of shared justice offered by the 20th-century Indian subcontinental philosopher Vinoda Bhave, a student of Mahatma Gandhi. The bhoodan, or "land gift," movement espoused the idea that the land belongs to all people and that no individual should own it (James, 2013). As such, the earth and its limited resources should benefit everyone, not a chosen few with power and wealth who may damage it for their own profit while harming others through their actions. For the field of instructional design, what some call instructional engineering (Simmons, 2015), it would be wise to consider how we use the earth by transforming its raw materials into educational tools just as environmental engineers and scientists do by understanding the complexity of decision, action, and consequence for impacted environmental ecosystems (Kahl, 2016). The issue of whether the tools can cause harm to other humans or the environment, as well as whether or how we should use learning tools made of natural materials, raises this to the level of an ethical question no different than whether we should create a learning game relative to its impacts of students (Warren & Lin, 2012). However, the environmental impacts of educational technologies are not a common part of our field's considerations as they are not commonly thought of in the same vein as physical, psychological, or emotional harm. Because of this separation, instructional designers and educators commonly have little knowledge of the impact of the manufacturing supply chain on our shared land or its people.

Ethics of Educational Technology and the Environment

In recognizing that the computer manufacturing supply chain makes a computer purchase a decision that is not ethically neutral, it is important to have models that consider additional costs and risks beyond the immediate purchase of the device. As we seek tools to foster learning improvement, the ethical question of “should we” becomes central to decision-making when starting to consider the environment and our responsibility for maintaining and protecting human health (Song & Li, 2014) as stewards of the earth’s natural resources (Alfred, 2009). There are always trade-offs understood between the environmental impacts compared with potential learning gains relative to the immediate financial costs of these technologies. As such, we propose building a differentiated total cost of ownership (TCO) model (Zachariassen & Arlbjørn, 2011) resulting from a life-cycle cost analysis (LCCA) approach offered by Farr et al. (2016). This combined model goes beyond simple educational outputs to help decision-makers better consider the environmental impacts of the whole computer manufacturing supply chain rather than using an end-point financial calculation that oversimplifies the externalities of climate and ecosystem impacts and unaccounted for global cost drivers that should ethically complicate their purchase choices (Ellram, 1995).

Methodology

This section will explain the methodology used to estimate the e-waste, energy, and C02 production from technology adoptions at scale in U.S. public schools and higher education institutions. These research methods come from supply chain and operations management analytic approaches (Meindl & Chopra, 2010) to build aggregate, long-term models of current and long-term outcomes from resource uses. From these, we will also incorporate other financial costs to build out a total cost of ownership planning model from Farr et al.’s (2016) life cycle cost analysis (LCCA) that is modified to incorporate environmental impacts as part of the ethical responsibility of educational managers to consider.

Modified Life Cycle Cost Analysis: Incorporating Environmental Costs

Farr et al. (2016) provided a useful research process for creating a cost model with technology. This process is our starting point for a modified life cycle cost analysis incorporating environmental costs not commonly captured in business models. The following are the stages with descriptions that include our changes to accommodate environmental considerations:

1. Life cycle cost analysis requirements: This phase includes understanding stakeholders, which in our model includes a) instructors, b) students, and c) the environment. It also includes examining the technologies and the processes associated with their creation, from raw materials extraction through disposal.

2. Formalize the study: Collect and normalize data, including cost estimates. Create likely scenarios for modeling that reflect the reality of environmental impacts from technology manufacturing, acquisition, use, and disposal. Develop output metrics reflective of all forecast costs.
3. Conduct study: Formally estimate acquisition costs (i.e., basic financial aspects) and environmental costs (i.e., raw materials mining impacts, transportation-related pollution, manufacturing-related environmental costs, etc.) Create related financial and environmental cost risk profiles—detailed bottom-up cost estimate.
4. Document study: Develop risk analysis profiles for different settings/systems of interest. Locate needed data sources, conduct analysis, and report results for financial and environmental costs.
5. Stakeholder feedback: Explore whether the degree of financial and environmental risk will change the technology choices of your clients/instructors/institutions.
6. Life-cycle cost estimate: Calculate total cost of ownership, including environmental costs, risk profiles, and recommendations to mitigate the risk of harm.

The following section presents our approach to using life-cycle cost analysis that incorporates considerations of the environment and includes the creation of equations that can be employed to better understand the ecological impacts of an educational technology's choice from beginning to end of the supply chain, considering how a computer's materials move from idea to mining, manufacturing, use, and disposal.

Findings

Our results illustrate the environmental impacts of educational computing and give readers a model for studying the impacts of a potential adoption on their local setting. The findings are structured in alignment with Farr et al.'s (2016) LCCA stages to offer a coherent linear process. Environmental impacts resulting from each stage are estimated based on current costs reported in conservation-focused engineering research reports from researchers with expertise in calculating waste and pollution effects from manufacturing and use.

Stage 1: Life cycle cost analysis requirements for the environmental impacts of computer production and use

The first stage of the process establishes the basic requirements for performing the life cycle cost analysis regarding the environmental costs of producing a common educational technology requirement for institutions: the laptop computer. Understanding these costs begins with a review of the computer production process and supply chain. The device manufacturing process starts with the mining and refining raw materials needed to make computer parts. Stations refine materials into usable forms, and large trucks transport loads from one facility to the next, generating air pollution and distributing waste in local soils and water (Marjovvi et al., 2022; Brodny, 2020; Zhang et al., 2015; Glodek et al., 2010) Further, analysis requires including the significant energy (Lenhardt, 2017; Williams, 2014), water (Agana et al., 2013), and human resources (Mmereki et al., 2016; Han & Liao, 2010) required to manufacture these devices. Once constructed, a modern, low-cost laptop (e.g., Chromebook) tends to rely on internet connections, adding energy and environmental pollution risks resulting from the use of large, energy use intensive, heat generating datacenters (Sovacool et al., 2022; Lenhardt et al., 2017). However, server farms' exponentially growing energy needs (Lenhardt et al., 2017) require electricity, often from polluting sources like coal or gas. The environmental impacts of technology choices commonly hide from the users behind dashboards and computer screens that display our educational applications.

Stage 2: Formalize the study

The study in our model is motivated by needing to understand the impacts of educational technologies from the perspective of the environmental costs beyond the simple financial calculations to buy needed devices (e.g., a new laptop costs USD $300). A driver for this study is the continued global growth of capitalist economies that rely on extractive industries to manufacture and transport new devices. However, there is likely little awareness on the part of instructional designers and other educators regarding negative short or long-term environmental impacts resulting from the computer manufacturing supply chain's energy and pollution on environmental and human health. For example, growing cases of asthma and other lung diseases due to air pollution implicate the materials and energy production needed to power computers (Sivaramanan, 2013), plastics are increasingly detected in the food supply (Lusher et al., 2017), along with human endocrine disrupting phthalate esthers used as a flame retardant in devices being present in the soil, vegetables (Wang et al., 2015), and marine ecosystems (Baloyi et al., 2021).

Stage 3: Conduct the study

The study is intentionally broad in its focus on computers to give readers a sense of the total costs of ownership beyond the simple financial calculation regarding whether needed devices are affordable. For most technology solutions, the determination results from knowing whether one has a large enough budget to afford the number of desired devices. For our example, in his or her planning, an instructional designer seeks to purchase a rolling laptop cart and 32 Chromebooks, which are necessary for a class to play a series of educational science games. The Tripp Lite CSC32AC Multi-Device Charging Cart priced from Newegg.com currently costs USD $1,268, including shipping. From the same vendor, an 11.6-inch display Chromebook (2 GHz, 32 GB SSD) from HP or Lenovo costs USD $250. For 32 units, the total financial cost for the devices is $8000, and they commonly have a lifespan ranging from 2–3 years, depending on use intensity. The total financial cost of purchase, including the cart, is USD $9,268. This cost does not include the energy use of the devices during an estimated 3-year period or associated pollution, nor the financial or environmental costs of disposal at end-of-life. It is important to be good stewards of the environment and have a better sense of the real life-cycle costs of our educational devices when making decisions.

Computer production: Ethics of resource use and human costs in manufacturing

To better understand the life-cycle cost of a computer, it is important to start with the educational requirements and how those become technological ones that potentially require the manufacture of new devices. As with other complex physical products, computer production relies on a similarly multifaceted supply chain process starting with raw materials mining. Once materials are acquired, they must be processed into usable forms, eventually leading to the creation and transport of the finished product (Caddy & Helou, 2007) to an educational institution for instructors and students. These devices are then disposed of when they reach the end of their natural, usable life cycle (Jayaraman et al., 2019). Each aspect of the supply chain has different impacts on the environment and the humans involved in gathering, processing, assembling, transporting, or disposing of the products (Ekener-Petersen & Finnveden, 2013). The first aspect of the supply chain needed to produce our educational technologies, which is the mining of the raw materials, tends to harm the communities where the mines exist and the miners themselves (Kasulaitis et al., 2015).

Computer manufacture: High resource and human costs

There is often the assumption in the field of educational technology that the tools are neutral because our educational design intention is to support positive learning outcomes. However, it is important to recognize that our intentions are not divorced from the physical realities of computer manufacturing and transportation to our classrooms. The natural resource use (e.g., water, chemicals, fossil fuels) for even a single computer results in a loss for the communities in which they extracted for production or once the device reaches the end of its life cycle (Wang et al., 2012), is associated with industrial pollution (Jeong et al., 2021; Levinson, 2009), and has lasting effects on the environment far past the end of a device's usable life (Babu et al., 2007). To be good stewards of the earth's resources, we must behave ethically with our technological choices. Understanding and documenting the resources used and their environmental costs is important.

Stage 4: Document study

At this stage of the LCCA process, we use available research study data from engineering and conservation journals to build estimates for the environmental costs associated with device manufacture to understand the ethical aspects of our choice betters when using technology to support educational outcomes. Doing so gives us an idea of the impacts of technology use at scale in educational institutions. It also helps better frame the ethical questions regarding the impact on the earth and the humans directly or indirectly impacted by our choices.

Device Production Calculated Simply, but High Environmental Costs

Due to restrictions on the length of this piece, we will continue to focus on the environmental impacts of computers since they are the most common educational hardware technology employed in schools, universities, and corporate settings. Implementing tools at scale does not commonly consider the environmental materials involved in their production. As a starting point for what is needed from the environment to make a single computer, the following table provides an estimate of the raw materials required to make a single computer (Bridgen & Webster, 2007). While this is an older number, it is one of few available and remains commonly used in information technology engineering to estimate computer production materials costs, although due to some efficiencies gained over time in manufacturing, the water use may be as little as 1.8 tons today (Agana et al., 2013).

Table 1

Materials used to produce one personal computer (Generic)

Material Used	Unit	Amount used
Water	Tons	1.5
Chemicals/ Raw materials	Pounds	48
Fossil fuels (for energy production and transportation)	Pounds	530

This table only estimates the natural commodities needed to manufacture a machine and does not consider additional costs for mining equipment, energy use (e.g., diesel fuel), or pollution. The water involved in manufacture must be fresh groundwater to avoid contamination during the industrial processing of materials, reducing available clean drinking water in the communities used for computer manufacture (Bretzler et al., 2017; Sankhla et al., 2016). To produce enough machines for a 32-student classroom, we aggregated the environmental resource costs indicated in Table 2.

Table 2

Materials used to produce enough computers for one classroom (Generic)

Material used	Amount per unit	Calculated resources needed per classroom (32 units)
Water	1.5 tons	48 tons
Chemicals	48 pounds	1,536 pounds
Fossil fuels	530 pounds	16,960 pounds (@ 8.5 tons)

This natural resource use is high, and the freshwater and chemicals are often not recoverable in the manufacturing process (Agana et al., 2013; Baloyi et al., 2021; Ekener-Petersen & Finnveden, 2013). For example, computer manufacturing may harm the environment and people in it when flame retardants make their way into aquatic ecosystems due to synthetic organic chemicals like phthalate esters found in computer plastics (Baloyi et al., 2021), releasing propylene into the atmosphere (Morgott, 2018), and dispersing sediments when transporting by truck (Jeong et al., 2021). To mitigate this problem, companies increasingly seek to capture chemical residues in wastewater and other sources, though this process is difficult and expensive (Agana et al., 2013; Dino et al., 2020). To better understand the impacts of using these materials on the environment and the people mining them, it is important to break them down into finer parts and understand their impact on the environment and the humans in it.

Raw Materials: Measuring Mining Impacts, Transportation, and Refinement

When engaging with a laptop computer, instructional designers, instructors, and students likely think of it as a whole machine rather than the sum of its parts. However, each component of that machine started its life as separate raw materials, often mined in countries with minimal worker safety protections (Phillips, 2016). Companies transport bits of the earth like crude oil for plastics, sand used to make glass, and precious metals for circuit boards to manufacturing plants for transformation into processed, usable forms. However, moving these components also deposits toxic elements into soils and the air through vehicle exhaust (Marjovvi et al., 2022). Once moved to the new location, the raw materials are made into plastic, lead, glass, and other processed materials. Then, these potentially toxic elements (PTEs) are released on their way to a location for assembly by a manufacturer of computer components. When such pollutants enter the air, soil, and water, they are inhaled, ingested, or enter the body through the skin, negatively impacting human health (Jeong et al., 2021). Table 3 presents the kinds of materials present in computers (Bridgen & Webster, 2007).

Table 3

Estimated amount and kind of materials present in a 3.7 pound Samsung Chromebook 4 (Samsung Group, 2022) 7 lb. device

Material	Precious metals	Plastic	Iron	Glass	Lead	Aluminum	Copper	Other (Chromium Mercury, etc.)	Totals
%	.02	23.0	20.47	24.8	6.3	14.17	6.93	4.3	100%
Translated weight (lbs.)	.00074	.851	.757	.918	.233	.525	.256	.156	3.70 lbs.

Although highly toxic materials such as cobalt or chromium are present in a computer only in small amounts, they remain harmful in low concentrations (Sankhla et al., 2016). However, other materials, such as plastics, are present in high amounts. They become more harmful when treated with flame-retardant phthalates that function as human endocrine system disruptors released in higher amounts when heated during use, harming human reproductive systems, especially in children (Kasulaitis et al., 2015; Babu et al., 2007). Each material has specific uses in computers that allow them to function (Babu et al., 2007); however, each material also has health impacts shown in Table 4 that remain little discussed in the field of learning technologies.

Table 4

Computer materials, uses, and related potential adverse health impacts (Babu et al., 2007)

Hazardous material	Computer use	Health impacts
Antimony	Semiconductors; flame retardant	Long-term impacts include lung and heart disease
Arsenic	Circuit boards, LCDs, chips	Carcinogen-causing skin, liver, and other cancers
Bromine	Flame retardant	Thyroid problems, neurobehavioral disorders, liver tumors, and immune system disruption
Cadmium	Chip resistors, semiconductors, infrared, cables, wires, circuit boards	Kidney disease, liver, heart disease, bone loss
Chlorine	Used to make PVC and PCB plastics	Inhalation can lead to vomiting, coma, and possible death
Chromium (hexavalent)	Corrosion inhibitor on circuit boards	Nasal and sinus cancers, kidney and liver damage
Cobalt	Rechargeable batteries, disc drives	Causes asthma-like diseases, shortness of breath
Lead (Pb)	Soldering to join chips and components	Anemia, weakness, damages kidneys, brain, and nervous system, and is fatal at high levels
Mercury	Batteries, circuit boards	Toxic to the central, digestive, and peripheral nervous systems, lungs/kidneys, possibly fatal
Phthalates	Power cable coating	Toxic to human reproduction; changes in sex hormone levels, altered genital development
Polyvinyl chloride plastic	Computer casing	Congenital disabilities and damage to the brain, heart, liver, kidney, and skeletal system

Each toxic material can cause negative health consequences for those mining the materials, those transforming the materials in factories, during use, and again once the device reaches its end of life during the recycling and disposal process (Sankhla et al., 2016; Nuss & Eckelman, 2014).

Human Resource Costs in the Device Supply Chain

Beyond the direct impacts of mining and secondary effects on the environment, the manufacturing supply chain impacts humans living in resource-rich areas (Leuenberger et al., 2021; Amaral-Zettler, 2019). When natural resources are discovered, especially in indigenous and low-political power communities with few legal protections, companies historically work with local and national governments for access to raw materials (Alfred, 2009) following a neocolonial model (McKenna, 2011), engaging in forced relocation so they can access fossil fuels and other needed manufacturing resources (Birch, 2016). This approach meets the needs of the capitalist economic system and its ethics; however, it creates health, environmental, and economic harm to communities when extreme weather events later destroy homes, natural resources, and agricultural areas with increasing floods (Er Kara et al., 2021; Crimmins et al., 2016), soil and water pollution (Amaral-Zettler, 2019), and fires (Marjovvi et al., 2022). Further, the economic and political precarity of many people living in areas with natural resources means they are at elevated risk of receiving little financial benefit from exploiting the material in their region or may be exploited through low wages or slavery (Esouimeme, 2020; New, 2015). In addition, many mining operations in countries with high levels of political corruption and low regulation lead to unsafe working conditions and non-sustainable mining and processing practices that have caused considerable harm to human health, ranging from high exposure to carcinogens to increases in greenhouse gas emissions (Liu et al., 2016), in addition to other significant air, water, and land pollutants. With the growing need to mine lithium for computers and other electronic devices we use in educational technology, it is important to recognize that mining practices are chemically intensive and associated with high amounts of waste that are difficult to dispose of safely (Flexer et al., 2018) and the batteries are commonly non-recyclable. Considering the need for batteries in all laptops, instructional designers should plan to incorporate this disposal as an environmental ownership cost. Further, the energy needed for these batteries is associated with pollution because most of today's energy production systems still rely on fossil fuels such as coal and natural gas (Bakhshi & Sandborn, 2018).

Transportation on a Global Scale: Energy and Pollution Outputs

Every stage in the supply chain process involves using energy to power the extraction of natural resources, their transformation into usable forms, their manufacture into devices, distribution globally to the locations of use, and transport once a tool reaches its end-of-life. Each stage in computer manufacturing has different energy intensity levels that require accounting for environmental use costs (Williams, 2004). Such consideration is needed because the financial models that produce the price educators see tend not to account for social and environmental costs. Under the pollution haven hypothesis (PHH), this situation exists because of lax environmental legal frameworks in countries where such work occurs and the reality that low-priced products rely on highly polluting, low-cost energy sources for manufacturing and transporting goods (Rezza, 2013). A computer's life-cycle energy use tends to be much higher during production (81%) than during active use (19%) locally (Williams, 2004), hiding this negative environmental impact from most technology adopters. Significant carbon emissions occur in the transportation of products, resulting in negative environmental impacts tied to climate change (Er Kara, 2021; Bazan et al., 2015). However, while a smaller component of energy use and pollution, it is important to consider the energy intensity of these devices throughout their lifecycle.

Energy and Pollution Impacts from Computer Use

The environmental impacts of using computers relative to energy use and associated pollution are presented in this section to illustrate the impact of choice to increase technology adoption. CO_2 emissions per KwH, an average of 1.4 tons of CO_2 per kWh for non-renewable sources, inform pollution estimates (Belkhir & Elmeligi, 2018). The following equation determines power consumption (kWh) per number of computers (n=32) included in the planning for the educational technology implementation example of a laptop cart and commonly available Chromebooks.

> *Where:*
>
> n_1 *= Number of computers per school campus per period*
>
> E_c *= Energy use per computer unit*

Table 5 provides energy use and CO_2 estimates for a modeled single classroom 1:1 laptop implementation based on current power use and pollution statistics from the U.S. Energy Information Administration's (2021) estimates to create both one- and three-year profiles, with the latter being the expected life of a well-maintained laptop.

Table 5

CO_2 increase estimates for all campuses in a sample Chromebook cart implementation

Computer type	Power use by 32 computers per year (kWh)	CO_2 lb./ kWh)	Annual estimated CO_2 pounds per machine	CO_2 tons per model implementation (32 devices)
One year	30	.85 CO_2 pounds	42 pounds	1,344 tons
Three years	90	.85 CO_2 pounds	156 pounds	4,032 tons

Environmental Impacts of Computer Disposal

At the recycling and computer disposal stage, there are additional ethical concerns. Here, we discuss the policy challenges related to computer disposal at end of life, how e-waste impacts water, air, and earth (Brigden & Webster, 2007), and past or current impacts of recycling in countries like China that have been responsible for taking waste for processing from the U.S., Europe, and elsewhere for the last 15 years or more. While the U.S. recently proposed a recycling plan (U.S. Environmental Protection Agency (2021), it is likely with current weak state and federal laws that devices will not be recycled safely, and electronic waste will end up in landfills locally and in those of other countries with limited environmental protections (Marjovvi et al., 2022; Jeong et al., 2021; Levinson, 2009). Educational institutions should seek sustainable solutions to mitigate the negative impacts of e-waste by managing and minimizing their intake of new equipment, maximizing the life-cycle of devices by purchasing more sustainable products, and measuring their environmental impacts annually and over the lifetime of a technologies' use relative to learning gains to determine if their technology purchase and use plan leads to more effective learning outcomes achieved with greater environmental efficiency (Singhal et al., 2019; Park et al., 2018). However, stakeholder feedback is important before moving on in the decision-making process.

Stage 5. Stakeholder Feedback

At this phase of the life-cycle analysis, it is important to ask stakeholders whether they are comfortable with the situation and its environmental impacts if the learning plan and related technology adoption go forward. Questions should include whether impacted users believe the expected learning outcomes outweigh the likely environmental impacts of purchasing the tools, whether there is an adequate sustainability plan for maximizing the learning value and life-cycle of needed devices, and whether they see ways to minimize the need for new technologies. After using stakeholder feedback to capture feedback and make changes to the plan, build a total cost of ownership model with environmental considerations.

Stage 6. Life-Cycle Cost Estimate: Build a Model of Total Cost of Ownership with Environmental Considerations

Using the resulting data and the Total Cost for Society framework (DeClerck et al., 2018), the following is a total cost of ownership model that adds environmental costs for manufacturing and school energy use and projected pollution from different levels of technology adoption, as well as safe disposal costs (Groot et al., 2014). The most complex stage, total cost of ownership, starts with accounting for simple financial costs for purchase. Most immediate to the educational user, we include the number of devices and their energy and pollution costs directly impacting the institution. The model then asks for a calculation of immediate environmental extraction impact assessment (i.e., mining energy use and associated pollution, unrecoverable mining waste, transportation, etc.) followed by the analysis of long-term extraction community costs (i.e., community health impacts from pollution, environmental damage, clean-up costs, climate impacts from flooding, fire, etc.) Next, planners should consider environmental impacts resulting from energy use and pollution during manufacturing and production phases, including transportation (i.e., energy use, soil, air, and water pollution). Next, one should consider point-to-point product transportation environment impacts for each other supply chain stage where materials or finished products are moved (i.e., manufacturer to distribution hubs to users' institution). Finally, the total cost of ownership incorporates the environmental and financial costs for safe recycling or disposal. The following mathematical calculation includes many environmental costs, though it is not exhaustive.

Where:

n_1 = *Number of computers*

E_c = *Energy use per computer unit*

P_c = *Annual C02 generate per computer unit (est. .87 tons)*

C_{ee} = *Immediate environmental extraction costs*

C_{el} = *Long-term community environmental extraction costs*

C_{em} = *Immediate environmental extraction costs*

C_{elm} = *Long-term community environmental extraction costs*

C_t = *Immediate environmental extraction costs*

C_{et} = *Long-term community environmental extraction costs*

C_{df} = *Financial disposal costs*

C_{de} = *Environmental impact disposal costs*

Once the total costs are determined, the instructional planner should compare these costs with expected learning gains. This approach allows a determination of the trade-offs between environmental impacts, financial costs, and possible learning gains. If a designer or educational manager determines that the benefits outweigh the costs, moving forward with technology adoption is deemed justifiable.

We recognize this is a complex calculation that is likely daunting to employ for an instructional designer or educational manager. While it may be too challenging to use, our purpose in providing it is to illustrate the high complexity of the supply chain and the commonly hidden environmental impacts that result from it. A simpler calculation for everyday use to get a sense of one's likely impact from educational computer acquisition is as follows:

Where:

n_1 = *Number of computers*

E_c = *Energy use per computer unit*

P_c = *Annual C02 generated per computer unit (est. .87 tons)*

C_{se} = *Total supply chain environmental impacts*

C_d = *Environmentally safe disposal costs*

Again, compare this estimated total cost of ownership with the estimated educational benefits of the tool over its entire lifetime. While it will not be exact, the goal is to help educational designers and managers make better decisions as to whether to purchase computers and in what quantity to balance the costs with possible benefits.

Discussion

The capitalist philosophy responsible for creating today's linear, consumption-driven economy is a primary driver of environmental harm today (Alfred, 2009). As such, we offer a technology planning strategy for instructional designers and educators based instead on indigenous views of social justice in which it is ethically necessary to "recognize that the earth has an inherent value, beyond human needs" (Alfred, 2009, p. 85). Therefore, our recommendations recognize that our devices start as raw materials mined from the planet. Each phase of the device life cycle, including manufacture, transport, use, and disposal, has additional environmental costs that we, as designers and educators, have an ethical responsibility to minimize.

Incorporating the Environment in Technology Adoption Planning Using Stewardship Philosophy

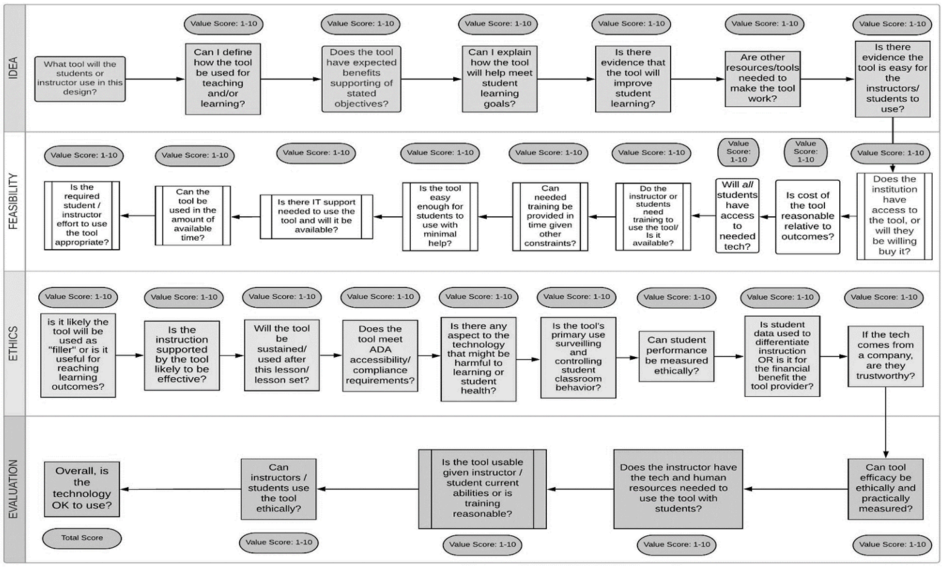
In this section, we provide a recommended planning model that incorporates total cost of ownership to help make the estimated environmental and financial costs transparent to managers before adopting technologies at scale. Knowing these costs can help designers, instructors, and managers make more informed decisions regarding their environmental impacts relative to evidence-based projected learning outcomes. As with other instructional design process models, a strong analysis is important for deciding to proceed with a plan.

Analysis

The analysis process to follow when determining the impact of a technology choice on the environment and humans is complex. It is important to determine the audience for the tool and whether it is appropriate to the intended learning tasks by evaluating the soundness of the idea, the feasibility of implementing the tool, and whether it is ethical to use it based on several factors related to students. The Ethical Choices with Educational Technology (ECET) Instructional Design (ID) technology evaluation choice framework (Beck & Warren, 2022) is one such tool for making this determination before choosing to use a tool (see Figure 1).

Figure 1

ECET Instructional Design (ID) Technology Evaluation Framework



Note the third component of the Ethics lane. This question helps instructional designers determine whether the application uses the tool once or if a sustainable plan exists to continue its use beyond the planned, current lesson. The framework should help instructional designers think through ideas, especially ethically. The addition of the environmental consideration is one small effort to drive sustainability thinking during the educational planning process and to help recognize that ethics should incorporate the environment as a stakeholder if we are to be good stewards of the earth, as proposed by Alfred (2009).

Further, before determining the potential environmental or human harms of adopting technology, designers must know what tool faculty and students will use and at what scale to achieve intended learning outcomes. Each chosen technology will have a different environmental impact depending on its size, raw materials and their source location, manufacturing processes, transportation costs, energy consumption, expected usable tool life, and other variable factors (Su et al., 2019).

Units needed to achieve learning outcomes

Another consideration with the tool choice is the number of units needed to achieve the expected learning outcomes, which can vary significantly based on the scale of the intended learning project. Historically, our educational technology field has pushed for a 1:1 device-to-student ratio because this is the best possible choice for learning outcomes (Stone, 2017). However, this idea fails to consider the environmental costs that result from manufacturing, using, and disposing of devices once they reach their end of life (Yi & Zhang, 2018; Williams, 2004). Each machine that we can avoid making and adopting reduces myriad environmental harms, so minimizing the number needed to achieve learning outcomes should be the first consideration a designer or educator makes.

Consider Environmental Harms from a Device

When considering the technology choice, it is important to consider device construction and the harms in mining, refining, manufacturing, and disposing of a device. Some companies think through reverse logistics with their devices to determine how to reclaim, reuse, recycle, or dispose of a device's materials at its end of life (Sovacool et al., 2020; Rahman & Subramanian, 2012). This information may be found on a manufacturer's website, though not all include it, requiring additional research work on the seeker's part. However, other companies fail to incorporate this thinking in their development planning or intentionally choose materials to make the device as cheaply as possible. Educational environments tend to choose these devices because of the price point. Such practices often result in materials that are more harmful to the environment at some stage in the supply chain.

Additionally, manufacturers intentionally prioritize compacted designs that are harder to break down for recycling or prevent upgrading and to extend usable life, increasing the number of units sold and growing profits at the expense of the environment. Designers and instructors should spend time examining each company's approach to manufacturing devices and look at the materials composition when possible to find and include machines with materials that have the lowest long-term environmental harm at each stage in the mining, manufacturing, transportation, use, and disposal life cycle (Su & Sun, 2019). Even if the immediate cost may be higher, the financial total cost may be lower because of an extended life cycle, or the environmental costs are fewer thanks to reusing, reclaiming, or disposing of safely.

Plan for the Entire Life Cycle of Each Device

Instructional designers and instructors tend to think through what they want from devices and how many will help them achieve instructional outcomes. However, to maintain an environmentally ethical attitude, one's planning should consider the entire life cycle of the device from the moment we choose to use it to how we will lengthen its life and how it will be disposed of safely.

- What are the learning affordances/benefits of the tool?
- What are the material characteristics of the technology?
- How can I minimize my needs with the tool (e.g., energy consumption)?
- How can I use this tool in a variety of ways that provide maximum benefits to the users?
- How can I maximize the life of the tool?
- What is my plan for disposing of these tools (e.g., recycling, safe disposal)?
- What is the plan for ensuring transparency in tool disposal at end-of-life?

If a major goal of taking an ethical attitude is to minimize our environmental impact as educational tool users, only strong planning to reduce our impact can result in reduced harm. These questions act as a starting point for the planning process and ask us to conduct research to identify the consequences of our decisions and actively take steps to mitigate harm. However, as you work through your educational systems and processes, you will likely find new questions. Shifting one's mindset to balancing the benefits with the total costs provides a designer or educator with a fuller perspective on the environmental impacts relative to possible learning improvements. This view considers real-world trade-offs necessary for a holistic ethical view.

Implications, Limitations, and Next Steps

This section reviews practical implications for ethical thinking using an environmental stewardship philosophy during technology planning. From this perspective, we offer practical recommendations for engaging in ethical thinking and active environmental harm reduction. Finally, we note limitations to the stewardship approach and future research that can test the model in the real world.

The First and Most Persistent Question: Should I?

From an ethical perspective, the first question we should ask ourselves before creating a learning plan that requires technology is “Should I?” (Warren & Lin, 2013). Too often, our interest in novel or everyday technologies and what we think they afford drives us to adopt them when less technology-intensive options may be as or more effective. Therefore, a necessary question is whether it is possible to implement the instruction and learning activities without a tool or with one already present. Asking this essential normative question at the outset of our technology and learning planning process can help eliminate potential environmental and human harm.

Practical Recommendations for Environmental Harm Reduction

Before choosing to use a technology, it is important to recognize that there will be some real, measurable harm related to technology adoption. With any device, these may be hidden behind digital ordering walls that obscure them, making them hard to recognize. However, these harms will negatively impact the environment or the people who make them at various points along the supply chain, during transportation to your location, and while using the device. There will be additional quantifiable effects at its end-of-life disposal. As such, we have some recommendations for instructional designers to consider in reducing the harms of technology adoption in any organization, especially educational ones.

Once choosing to adopt new technology as part of a learning plan, we suggest taking steps you may be familiar with from experience, starting with the 3Rs recommended by Mmereki et al. (2016). The first approach is reducing the number of technology units needed or selecting one with a lower pollution footprint. Next, we recommend finding ways to reuse the technology and maximize its value for educational projects throughout the educational setting. Once a technology is no longer usable for its intended purpose, the next strategy should involve recycling materials feasible for repurposing or safe disposal of anything unusable.

Harm Mitigation Strategy 1: Reduce

When deciding how to move forward with an instructional technology implementation that is responsive to reducing negative environmental impacts, it is important to start by forecasting the minimum number of units needed to achieve learning outcomes successfully. As part of this planning process, one might also consider calculating the environmental impacts of different numbers of units to achieve the required learning outcomes. The goal of this approach is to constrain negative outcomes resulting from technology production, use, and disposal phases (Mmereki et al., 2016). Next, the designer or instructor should consider reducing the need for technology in the plan.

For example, a pure unit reduction approach can work if not all students require laptops concurrently in a social constructivist-based team activity where one student takes notes or records findings, reducing the 37 required units to seven by organizing students into five groups. An added benefit to educational organizations is that this approach reduces implementation costs. By contrast, a lower total environmental cost approach might work if all 35 units are needed. In this case, select options for technology with the lowest energy use and associated pollution and the best physical materials from the lowest impact mining while ensuring units can perform adequately to achieve learning outcomes. A mix of approaches also works; seeking the lowest environmental impact units combined with a unit minimization approach should significantly reduce the project's environmental impact. Once the technology is acquired, the second strategy implemented should ensure that a tool is used for as long as possible so that the environmental impacts from the technology choice have educational benefits for the longest possible period.

Harm Mitigation Strategy 2: Reuse

Three increasingly popular approaches to minimizing the negative impacts of technology on the environment are 1.) repurposing end-of-life electronics equipment (Coughlan et al., 2018) or 2.) taking part in a robust but challenging global shift in mindset to the whole economy and the role of educational institutions in it by adopting the concept of an in-spiral supply chain that complements a circular economy (Valero et al., 2020). The first approach, repurposing equipment, can be done by taking older laptops and using them minimally for activities such as web browsing (i.e., "thin clients"), like how Google Chromebooks are used today (Dino et al., 2020). Another option is to find ways to cheaply improve the internal components of machines that can be modified to extend system life (e.g., add RAM, new hard drive), providing them to students with lower computing needs, such as elementary school children aged 5–12. If the machines are not usable within the institution, participating in the circular economy is another option to reduce negative impacts (Burneo et al., 2020).

Sariatli (2017) explained that "The natural consequence of cheap material / expensive labor is the common neglect of recycling, reusing, and putting much emphasis on waste" (p. 31). Put simply, the take, make and dispose model has had "consequences for society, a negative impact on health and contributes to climate change [. . .] we need a system that functions properly – in which the circular economy replaces the linear" (World Economic Forum, 2019, p. 6). Contrasting with the linear economy, Geng et al. (2012) wrote that the circular economy is "an economy based on a 'spiral-loop system' that minimises [sic] matter, energy flow and environmental deterioration without restricting economic growth or social and technical progress" (p. 281). In the circular economic model, shared value redefines the functions of the world's corporations, for "the purpose of the corporation must be redefined as creating shared value, not just profit per se. This will drive the next wave of innovation and productivity growth in the global economy" (Porter & Kramer, 2018, p. 4), which requires integration of what Ekholm et al. (2016) defined as an ecosystem service-dominant logic. Using this mindset requires considering where any purchased technologies will go next in the economic or educational system, ensuring they have practical, maximized use value for society until they reach a point at which the materials must be broken back down and repurposed safely again. Another common environmental harm reduction strategy involves recycling as an individual strategy or combined with circular economy participation.

Harm Mitigation Strategy 3: Recycle with Planning, Tracing, and Measuring Impacts

A common recycling strategy schools, universities, and businesses have employed over the last two decades involves selling computers and other technologies that reach their end-of-life at low prices to private companies expected to recycle them (Gavronski et al., 2012). However, as we find in our institutions and others contacted, once selling these devices through an organization's facilities surplus unit or online partner, the chain of custody for that device ends. This problem results from a lack of recycling policy coordination across global supply chains among companies or governments (Sovacool et al., 2020) and couples with minimal transparency in the e-waste supply chain at end of life (Chen et al., 2019). In other words, we cannot trace these devices' locations and whether they are disposed of safely when they reach their final destination (Kumar et al., 2017). Further, even pyrolysis may not successfully reclaim plastics most commonly recycled, as common mechanical treatments do not work on plastics found in computers (Qureshi et al., 2020). As such, the instructional designer or instructor should work with their institution and community to develop a robust plan for recycling that includes a chain of custody extending to where the device is successfully recycled or disposed of without environmental harm.

Harm Mitigation Strategy 4: Plan to Dispose of Non-Recyclables Safely

There is little evidence that most educational institutions have plans for effective, safe disposal of non-recyclable components of electronic devices, meaning many devices end up in landfills. Further, well-intentioned technology planners know there are parts of even the most environmentally friendly computers that end up as pure e-waste that must be disposed of safely. Current laws in many countries fail to account for this challenge, so there is no guarantee of minimized harm when disposing of a machine that cannot be recycled. As a result, people in countries like India, China, Vietnam, and some African Countries (Tran & Salfhofer, 2018; Sivramanan, 2013; Gaidajis et al., 2010), who are involved in the process of stripping electronics for valuable metals, are harmed through informal end-processing of e-waste (Sankhla et al., 2016; Song & Li, 2014). Those countries often have few resources for mitigating environmental damage to the local earth, water, and air (Dino et al., 2020). However, China instituted its National Sword policy in 2018, reducing the amount of technology imported for recycling (Tian et al., 2021). This change has had consequences for countries like the U.S. and the U.K., where our recycling strategy for the last two decades has primarily been to ship our e-waste to other countries, leaving many communities and organizations with poor sustainable waste disposal strategies. It was only at the end of 2021 that the United States Environmental Protection Agency (EPA) announced a national recycling strategy focused on growing markets for waste, increasing material collection, reducing materials contamination, improving policies and programs nationally and internationally, and standardizing measures of recycling performance in communities, especially those carrying an unfair burden of the environmental costs of waste (United States Environmental Protection Agency, 2021). In the waste disposal and recycling planning domain, the field of conservation engineering spent the last two decades seeking to understand and model solutions for the safe disposal of toxic materials left over from technologies once they reach the end of usable life (Sovacool et al., 2022; Su & Sun, 2019; Williams, 2004; Joshi, 1999); however, that will be the focus of future studies.

Future Research

In the future, the field should research the growing problem of electronic waste left behind by instructional technology users and how successful educational institutions plan and operationalize their safe disposal strategies. For example, a single K-12 school district that adopts a 1:1 laptop initiative generates a minimum of 55 tons of e-waste every three years from the computers alone (Warren et al., 2022a). Further, there is no research on the e-waste and energy consumption of the many higher education institutions in the U.S. or globally, which leaves a gap in our knowledge about how we can reduce their likely negative environmental impacts through restructuring of educational facilities and technology used in support of their educational missions through the adoption of sustainable planning and energy production (Warren et al., 2022b). We know little about the environmental impacts of current K-12 or higher education sustainability policy on real-world ecosystem outcomes. Given this need, scholars should focus on how school districts cope safely with the waste generated from these initiatives. Such plans should address increased rising financial costs of technology and energy that continue to increase in response to global supply chain challenges due to cyber threats, climate impacts, decreased access to natural resources, high shipping costs, skilled worker shortages, and competition for labor (Er Kara, 2021; Crimmins et al., 2016; Manuj & Mentzer, 2008). In addition, it is important to understand whether instructional designers and educational managers (e.g., principals, higher education administrators, etc.) believe they have an ethical responsibility to consider the environment in their development planning, along with considerations of learning outcomes. Better understanding designers' perspectives can guide how we develop future training on how to incorporate an environmentally ethical perspective in the technology adoption planning process of which we are a part, helping shift mindsets from that of perceived neutral tool users to stewards of sensitive global resources with intrinsic value that should be protected.

Limitations

While centered on instructional designers and their ethical decision-making, this chapter rapidly covers highly complex manufacturing, environmental philosophy, and conservation engineering concepts. As such, we simplify concepts to help instructional designers and managers of technology become broadly aware of environmental and technological challenges; however, future work, communication, and ethical behaviors will benefit from exploring each topic.

Further, exploration of the supply chain's environmental impacts was limited to a single, small classroom to illustrate the principles. The framework requires testing in many contexts to determine its applicable value. We do not advocate for generalizing the framework to other settings or provide precise mathematical equations for calculating the total cost of ownership. A single laptop device has many variables (e.g., laptop construction materials, power use, energy source type, etc.), so our equations aimed to illustrate the complexity inherent in making an environmentally ethical choice about whether and what technology to adopt in education settings.

Conclusion

Having an ethical attitude towards the environmental impacts of technology requires understanding the complexity involved in their creation, transportation, use, and disposal chain. As such, there is value and a need to understand the environmental impacts of adopting a new technology beyond immediate use and potential learning affordances. As Hill (2017) explained, an ethical attitude toward educational technology can be conceived of by understanding that "[E]nvironmental protection means – or should mean – reducing pollution, making sustainable choices, and distributing the burdens and benefits of industrialization fairly among all populations, considering their current situations, their contribution to the harms being addressed, and the resources available to them" (p. 3). A major goal of this chapter was to illustrate the environmental harms inherent in our technologies and model how we can consider systematically reducing them during our instructional development process. By viewing environmental and human costs as part of an educational technology's total cost of ownership, instructional designers and educational managers should have a better sense of unaccounted-for costs that go beyond the immediate financial ones central to everyday decision-making. Using these models that integrate costs hidden behind ordering screens, whether for a single computer or a university-wide device adoption from a new vendor, we can better understand the complex outcomes of seemingly ethically neutral choices and make better decisions for now and the future.

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